Physica A 419 (2015) 23–28

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Analysis of natural time domain entropy fluctuations of synthetic seismicity generated by a simple stick–slip system with asperities

C.A. Vargas [a], E.L. Flores-Márquez [a,b], A. Ramírez-Rojas [a], L. Telesca [c,*]

[a] *Departamento de Ciencias Básicas, Universidad Autónoma Metropolitana, Av. San Pablo 180, Col. Reynosa, Azcapotzalco, México D.F. 02200, Mexico*

[b] *Instituto de Geofísica, Universidad Nacional Autónoma de México, Circuito Institutos S/N, Ciudad Universitaria, 04610, México D.F., Mexico*

[c] *Institute of Methodologies for Environmental Analysis, National Research Council, Tito Scalo (PZ), Italy*

HIGHLIGHTS

- Synthetic seismicity is produced by using an experimental stick–slip system.
- Entropy fluctuation δS of synthetic seismicity is used to study its Markovianity.
- The synthetic seismicity is non-Markovian for higher threshold magnitudes.
- The synthetic seismicity is non-Markovian for lower lengths of the time window.

ARTICLE INFO

Article history:
Received 18 July 2014
Received in revised form 22 September 2014
Available online 18 October 2014

Keywords:
Entropy
Natural time domain
Stick–slip system
Seismicity

ABSTRACT

In the framework of the information theory, entropy measures the level of disorder of a system or its uncertainty. Varotsos et al. (2004) introduced the concept of entropy in natural time domain as a discriminating statistics. In this paper, we analyzed the fluctuations of entropy, δS, of synthetic seismicity produced by an experimental stick–slip system in order to investigate its Markovian behavior. Our system, whose asperities are given by sandpapers of different granularity degrees, mimics the dynamics of tectonic plates. We found that δS is able to characterize the synthetic seismic process as non-Markovian for higher threshold magnitudes and lower lengths of the time window sweeping through the dataset.

1. Introduction

The interaction between tectonic plates and seismic processes is a complex phenomenon due to the existence of time, space and magnitude correlations. In order to understand better the dynamics of seismic processes, theoretical and experimental approaches have been developed in order to reproduce the main features of seismicity. The well known spring-block model, introduced by Ref. [1], considers the interaction between plates by means of masses connected by linear springs, to simulate the relative movement of the plates. Recently, Ref. [2] developed a stick–slip model, in which the relative movement of two rough surfaces (sandpapers) simulates the interaction between tectonic plates. In this experimental model the

* Corresponding author.
E-mail address: luciano.telesca@imaa.cnr.it (L. Telesca).

http://dx.doi.org/10.1016/j.physa.2014.10.037
0378-4371/

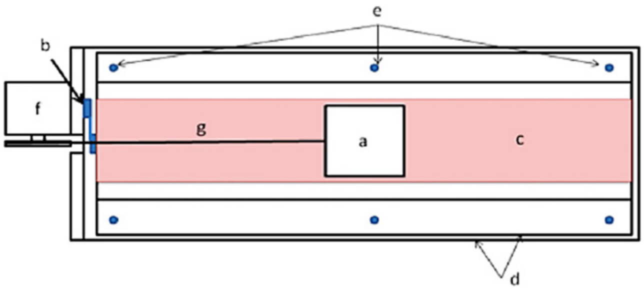

Fig. 1. Experimental setup (see text for details).

interaction between sandpapers, rugged surfaces moving in opposition to each other, produces displacements which mimic the real seismicity. Previous studies of this synthetic seismicity have been performed in terms of the Gutenberg–Richter distribution [2], of the correlation properties based on the detrended fluctuation analysis [3], and considering the order parameter defined in natural time domain (NTD) [4–8]. Therefore, the stick–slip model shows features of a complex system.

The entropy S is considered as a natural measure of complexity in deterministic and stochastic processes [9,10]. The fluctuations of entropy δS, defined as the standard deviation of the entropy S computed in the NTD were applied by Ref. [11] to identify possible Markovian behavior in time series. They found that δS can be used as discriminating statistics when it is computed for a time series and compared with that corresponding to the surrogates, obtained through a shuffling procedure, which does not change the probability distribution function and destroys all the correlations [12,13]. Their main result was that $\delta S/\delta S_{shuf} \neq 1$ indicates that the system is non-Markovian [11]. In this paper, we apply the discriminating statistics $\delta S/\delta S_{shuf}$ in order to detect Markovian behavior in the synthetic seismicity produced by the stick–slip model.

2. Experimental setup

The stick–slip model is aimed to simulate the interaction between two rough fault planes. Thus, we build up a frictional system subjected to a mechanical forcing. This experimental device is schematically shown in Fig. 1. The system consists of an aluminum block (a) of 0.1 m length, 0.1 m width, 0.025 m height, and 0.5 kg mass, which slides over a frictional surface with asperities (c), consisting of an aluminum track of dimensions 0.7 m length, 0.22 m width and 0.003 m height. The inferior surface of the block (a) and the aluminum track (c) are coated with sandpapers with different granularity degrees. Below the aluminum track, a low friction suspension system consisting of two glass plates was settled. The superior glass plate has a thickness of 0.009 m and rests on a set of steel spheres (e), with diameter of 0.004 m, which can roll over a second glass plate of 0.012 m thickness (d). All the suspension systems are placed over a metallic frame to maintain it in a leveled position. The object (b) is a charge cell (Omega LCL), which works as a bumper against the metallic frame and allows recording the force exerted by the inferior plate over the cell when the elastic rope (g) is kept in tension. The rope is a fishing string with a diameter of 5×10^{-4} m and a charge limit of 8.0 kg. The rope connects the aluminum block with the motor (f) through a pulley. To pull the block a CD-motor is used with speed control (Baldor CD5319) with two gearboxes of 60/1 in series connection. During the run the string is pulled with a constant speed of 0.0133 m/min resulting in a block displacement of about 0.6 m in 45 min. The charge cell was polarized by means of a regularized power source of 10 DCV; the cell sensitivity is 2 mV for each volt from the power source. In the experiment the maximum charge is 20 N, producing a signal of 20 mV. The signal of the charge cell was registered with a resolution of $\pm 0.5 \times 10^{-6}$ V by means of a digital voltmeter (Keithley 197A), and connected to a personal computer through a GPIB interface using a QBasic program. It used the voltmeter minimum sampling time of 0.33 s. Concerning the roughness of the interacting surfaces, the different asperities are indicated by the sandpaper granularity degree, low granularity degree meaning high asperity. For each experiment, the dataset were obtained by using combinations of different sandpaper granularity degrees, classified in agreement to the European Financial Planning Association (EFPA) (www.efpa-europe.org/) standard abrasives (sandblasting material abrasive 16 mesh Fandelli International Corporation commercial trademark, Houston Texas). The combinations of sandpapers (EPFA code) used in the experiment were AB (36–40), AE (36–80) and AH (36–220), where the first code corresponds to the granularity degree of c, while the second one to that of a. Both rugged surfaces moved in opposition to each other, and for each combination the experiment was repeated five times (runs from 1 to 5). For each combination we collected five datasets of the synthetic seismicity, each one after a run. The last dataset would describe the phenomenon of the wearing produced by the friction of the tectonic plates, equivalent to the aging between the plates.

3. Data analysis

The NTD approach was developed by Ref. [14] which extracts the maximum information possible from a given signal [15]. Given a sequence of N events (t_k, Q_k), where t_k is the occurrence time and Q_k is a quantity associated with the event (for instance, in case of seismicity, Q_k could the magnitude or the seismic moment of the event), the natural time is defined as $\chi_k = k/N$, where k represents the index of occurrence of the k-th event.